HIGH-GRADIENT S-BAND TEST LINAC FOR JAPAN LINEAR COLLIDER

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Abstract

A high-gradient S-band test linac was constructed as a development bench of the Japan Linear Collider. A single-bunch beam with 1.4×10^{10} electrons has been accelerated by the test linac at the maximum accelerating gradient of up to 84 MV/m. Energy spread of the accelerated beam was measured to be 2.1% (FWHM).

Introduction

The accelerating gradient planned for the Japan Linear Collider phase-1 is ~50 MV/m for main linacs and 20~30 MV/m for S-band injectors and pre-accelerators. The construction of the Accelerator Test Facility (ATF) has been started at KEK. The ATF is mainly composed of an 1.54 GeV S-band linac, a damping ring, a bunch compressor system and a final focus system.

As a first step, the construction of an injector part of the S-band linac has already been completed. It makes possible to accelerate a single- and multi-bunch beam at a high accelerating gradient. The test of multi-bunch beam acceleration was carried out at a gradient of up to 85 MV/m in July 1990 [1]. In that experiment, a peak beam current and a pulse width are 0.9 A and 0.2 μsec, respectively. At the maximum accelerating gradient of 85 MV/m, heavy dark current was observed and RF breakdown took place frequently. However, at the accelerating gradient less than 50 MV/m, the dark current was negligibly small and the stable acceleration was feasible.

Also, a systematic study of S-band high gradient structures have been carried out without the beam acceleration. The maximum gradient of up to 91 MV/m was achieved and detailed features of dark current was studied [2, 3]. In the present experiment, we focused to accelerate a high-current single-bunch beam at a high accelerating gradient.

Layout of the linac

The test linac consists of a thermionic electron gun, three subharmonic bunchers (SHB) of 119, 238 and 476 MHz, two single gap prebunchers, a traveling-wave buncher and an S-band constant gradient disk-loaded structure with a length of 0.6 m as shown in Fig. 1.

The thermionic electron gun uses an EIMAC-Y796 dispenser type cathode with an area of 2 cm^2, the maximum operation voltage of up to 240 kV [9]. Each three SHB is a standing-wave mode and half-coaxial type cavity with a single acceleration gap. The accelerating structure is a $2\pi/3$ mode constant-gradient type with 17 cells, input and output couplers which are manufactured using an electroplating method. The disks and cylinders were machined from high-purity OFHC copper blocks. The surface roughness of the beam hole was less than 0.3 μm, and that of the flat surface was less than 0.02 μm.

The structures were designed to obtain a gradient of 100 MV/m at an input rf power of 195 MW. The parameters of the structure are summarized in Table 1.

TABLE 1
Parameters of the 0.6 m Structure.

Phase Shift/Cell	$2\pi/3$	Constant Gradient
Structure Length	66.5	cm
Iris Diameter (2a)		
Input	1.8998	cm
Output	1.5900	cm
Cavity Diameter (2b)		
Input	8.172	cm
Output	8.124	cm
Resonant Frequency (f)	2856	MHz at 36.5°C, Vacuum
Quality Factor (Q)	11600	
Shunt Impedance (r)	62	MΩ/m
Attenuation Constant (α)	0.48	Neper/m
Peak Surface Electric Field / Axial Electric Field (Es/Ea)	1.9 ~ 2.1	
Average Group Velocity (Vg/c)	0.00445	
Filling Time (T_f)	0.475	μsec

Using these values, the accelerating field (E_a) without a beam is given as

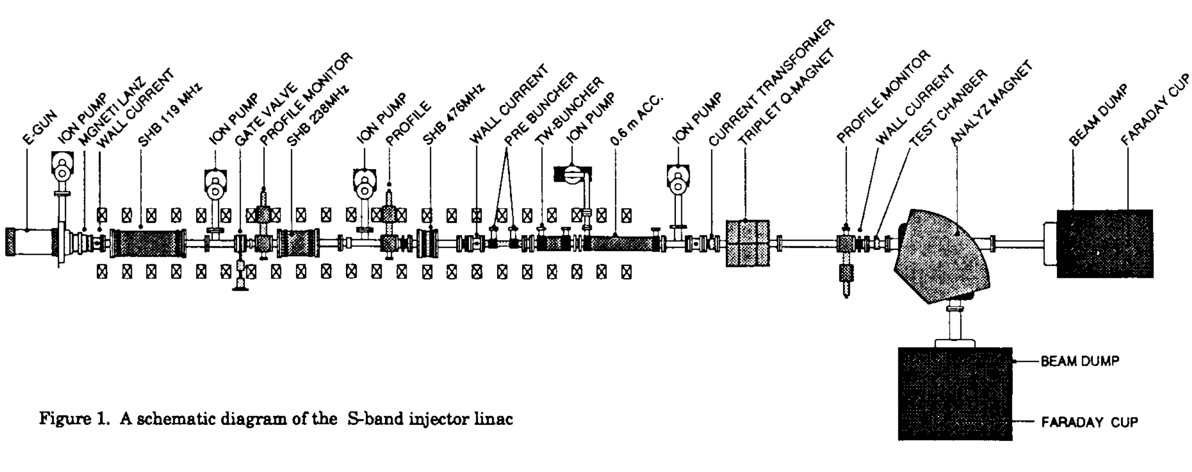


Figure 1. A schematic diagram of the S-band injector linac

$$E_a\,(MV/m) = 7.16 \times \sqrt{P_{in}\,(MW)}\,, \qquad (1)$$

where Ea is the accelerating gradient in MV/m and P_{in} is the input rf power in MW. The maximum surface field (E_s) at the disk edges is evaluated to be 2.1-times larger than E_a by a SUPERFISH.

The SHB's, prebunchers, buncher and 0.6 m-long structure are installed inside the 25 Helmholtz coils whose current can be controlled independently. The distribution of the axial magnetic field can be tapered from 150 to 700 Gauss so that the beam flows in Brillouin condition based on the calculation using a computer code PARMELA simulation.

The support gurder of the injector is a 9 m long and 0.67 m wide table with stopper edge for horizontal alignment. The flatness of the table surface is 36 µm/9 m. All the components could be aligned within a 100 µm accuracy by pushing to the alignment edge.

The rf-output from two klystrons (SLAC 5045 and TOSHIBA E3712) is combined with a 3 dB wave-guide type directional coupler. The maximum power of 200 MW at a pulse width of 1 µsec and a repetition rate of 50 Hz can be fed into the structure. The rf phase deviation and amplitude variation of the combined output were held to less than 2 degrees and 1% during any pulse, respectively. The klystron modulators [5] have been developed to drive both SLAC-5045 and TOSHIBA-E3712 klystrons. A small fraction of the combined power is used to feed the pre-bunchers and the buncher. The rf power of both the forward and reflected waves was monitored by dual Bethe-hole couplers with a coupling ratio of -70 dB. The transmitted power through a test structure of 0.6 m long was also monitored by a Beth-hole coupler and was terminated by an rf water load which was developed at SLAC.

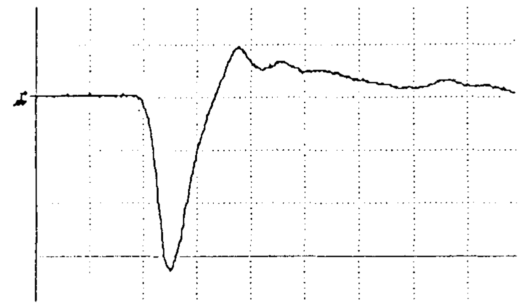
A magnetic spectrometer with a 90° bending angle was placed at a location after the structure which has a movable beam slit, and electrons were captured by a Faraday cup. The momentum resolution was set to 0.24% in this experiment.

The peak current and pulse shape of the beam were monitored by three wall-current monitors placed at each downstream of the electron gun, the SHB of 476 MHz and the accelerator structure, respectively. The wall current monitor has a time resolution of 200 ps. Two luminescent ceramic beam-profile monitors were mounted each downstream of the SHB of 119 MHz and the accelerator structure. Operation of this accelerator, such as the electron gun, the input rf power and the phase to the SHB's, the prebunchers, the buncher and the 0.6 m structure are controlled using a computer program.

Experiment of single-bunch acceleration

Generation of single-bunch

A fast grid pulse generator was developed to produce such a high current beam with a short pulse duration by utilizing avalanche transistors [6]. Using this fast grid pulse generator, the thermionic gun was operated at 1.96×10^{10} electrons with a full width of less than 700 ps, as shown in Figure 2. The cathode voltage was 170 kV. The vacuum pressure level of the gun was kept 2×10^{-6} Pa. In order to make an single bunch, two SHBs were used. As the generated beam could inject to the phase aperture of the 238 MHz SHB, we did not operate the SHB of 119 MHz. The 5 kW solid state pulse amplifiers are used to excite each cavity of SHBs. The amplitude and phase are stabilized by feed back loops within 1% and 1 degree, respectively.



500 psec/div, 2 A/div

Figure 2. Single bunched beam waveform of the thermionic gun.

Accelerating structure

For conditioning of the structure, rf pulses with a width of 0.8 µsec and a repetition rate of 50 Hz were applied. The wave guide system, the structure and the beam ducts are pumped down to 5×10^{-7} Pa. The vacuum pressure is monitored by cold cathode gauges (CCG) and B-A gauges. The CCGs are used as trip signals of klystron modulators during rf operation to protect the structure from a break down. The partial pressure of residual gases during the processing is monitored with a mass-spectrum analyzer.

During the conditioning, the rf power applied to the structure was controlled by a computer program to keep the vacuum pressure below 1×10^{-5} Pa. The trip level of the vacuum pressure was set to 1×10^{-4} Pa. Normally the vacuum pressure of the structure was around 5×10^{-6} Pa during rf processing at any rf power level. In this electroplated structure, a maximum gradient of 84 MV/m which correspond to 138 MW input power was attained after 200 hours of rf processing.

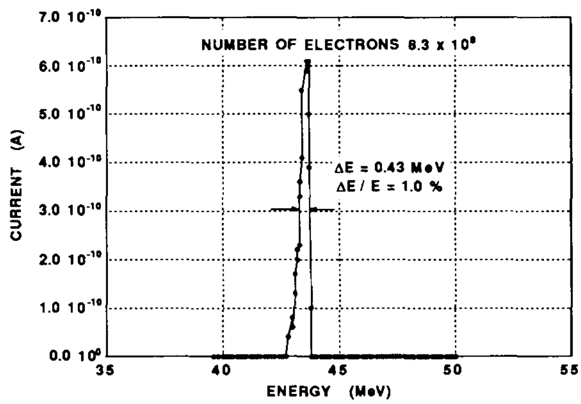
After the processing, high dark current observed by the current transformers and the profile monitor at over 70 MV/m gradient. At that time, rf trips by the break down occurred once a few tens of minutes. Around the 60 MV/m, the occurrence of rf breakdown reduced. Below the 50 MV/m, the dark-current emission could not be observed by the monitors and the operation is quite stable.

Beam acceleration

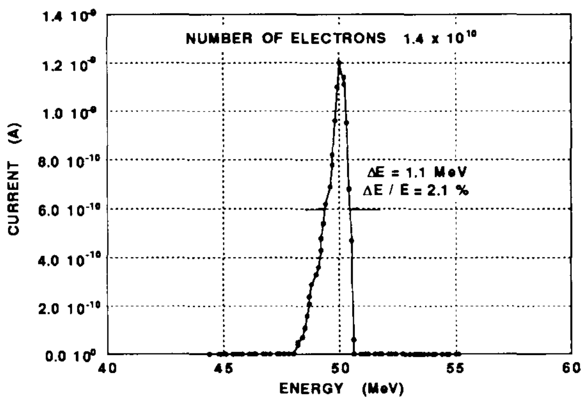
After the processing, a first experiment of the single-bunch acceleration was started at the gradient of 74 MV/m. The beam intensity of the gun was set to 1×10^{10} electrons. The optimum phase and amplitude of SHBs and bunchers were surveyed to minimize the signal width and to maximize the peak amplitude of the wall current monitors. The fine tuning of their phase and amplitude was carried to minimize the energy spread of the accelerated beam. As a result, the obtained energy spread was 1% with 8.3×10^{9} beam intensity at the exit of the structure (Figure 4-a). At this gradient, the beam acceleration was operated without break-down.

After a few day's operation, accelerating gradient was increased up to 84 MV/m which was the maximum gradient in the present experiment. The maximum beam intensity obtained at this gradient was 1.4×10^{10} electrons and the energy spread was 2.1% as shown in Figure 4-(b).

In order to obtain a high current, the grid bias voltage of the gun was lowered at the 84 MV/m



(a) Energy spectrum at 74 MV/m



(b) Energy spectrum at 84 MV/m

Figure 4. Energy spectrum of the accelerated beam.

acceleration. It produced the spread to the tail of beam pulse. That is the considerable difference of the beam parameter between 74 and 84 MV/m. Therefore, it seems that the increase of the energy spread at 84 MV/m directly come from the increase of longitudinal spread of the beam emitted from the gun. The detailed analysis is now carrying by using the PARMELA simulation. In this beam acceleration operation with high intensity, very fine machine tuning was required. In order to obtain the small energy spread of single-bunch beam and to increase the beam intensity, simulation of this machine as well as further systematic experiment is necessary. Also to confirm the bunch structure a bunch length monitor is under design.

Experiments under preparing

We have experiments under preparing such as two single bunch acceleration, high gradient acceleration test of 3 m long structure, the test of beam position monitors and wire scanning profile monitor. In order to investigate the effects of the high intensity multi bunch beam, the two single bunch acceleration experiment using two avalanche pulse generator is under way [7]. The 3 m long structure has been fabricated for ATF. To investigate the dark current effect on beam and maximum field gradient, the same test as the 0.6 m long structure will be done. As for beam monitors, prototype for JLC has been developed. The beam test using high intensity single bunch will be carried.

Summary

The 1.96×10^{10} beam with a full width of less than 700 ps was generated by the thermionic gun using the fast grid pulse generator. Single bunched beam of 1.4×10^{10} has been accelerated with the energy spread of 2.1% at 84 MV/m. At this gradient, rf breakdown occurred frequently. However, beam acceleration at 74 MV/m is fairly stable. It seems feasible to operate the accelerating structure at this gradient for the practical use after a reasonable processing time.

Acknowledgment

The authors wish to acknowledge Professors Y. Kimura and K. Takata for their continuous encouragement. This work could not be carried out without the support by Professors M. Yoshioka and J. Urakawa, the members of JLC study group, and also Mrs. T. Matsui and S. Morita of ATC corporation. The authors also wish to thank these people for their help.

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